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Automated Processing of Internal Ice Layer Dip in Radio-Echo Soundings

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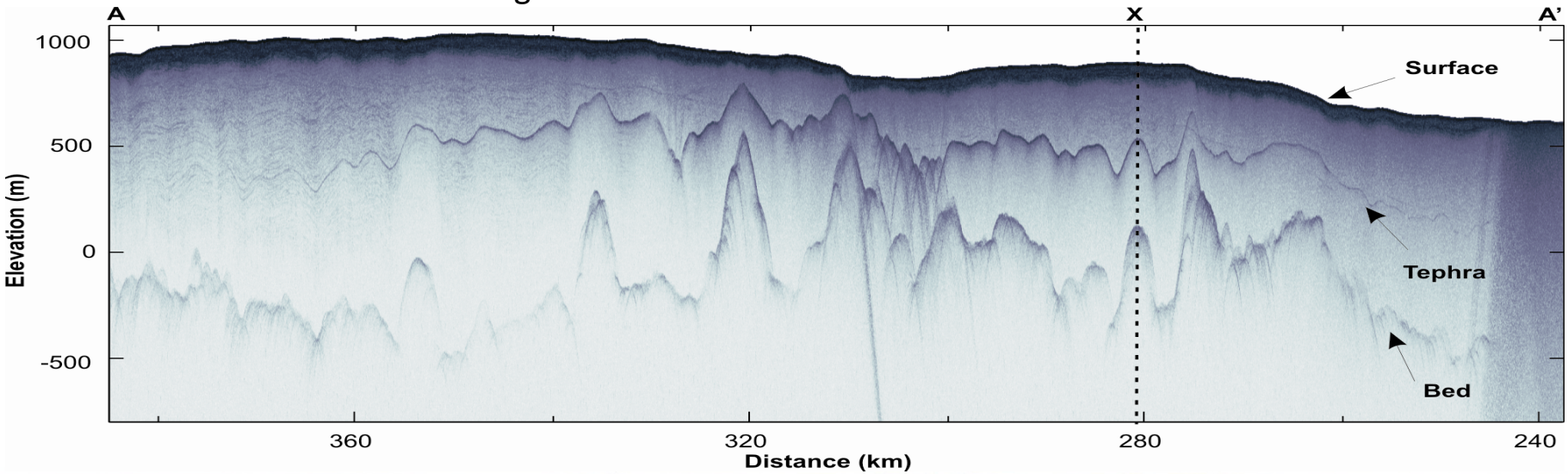
ARESP

Automated RES processing

- Internal layers are considered to be isochronous
- They provide a picture of the age structure of the ice and used to:
  - investigate changes in ice flow
  - flow modelling studies
  - calculate past accumulation rates
  - constrain ice core ages



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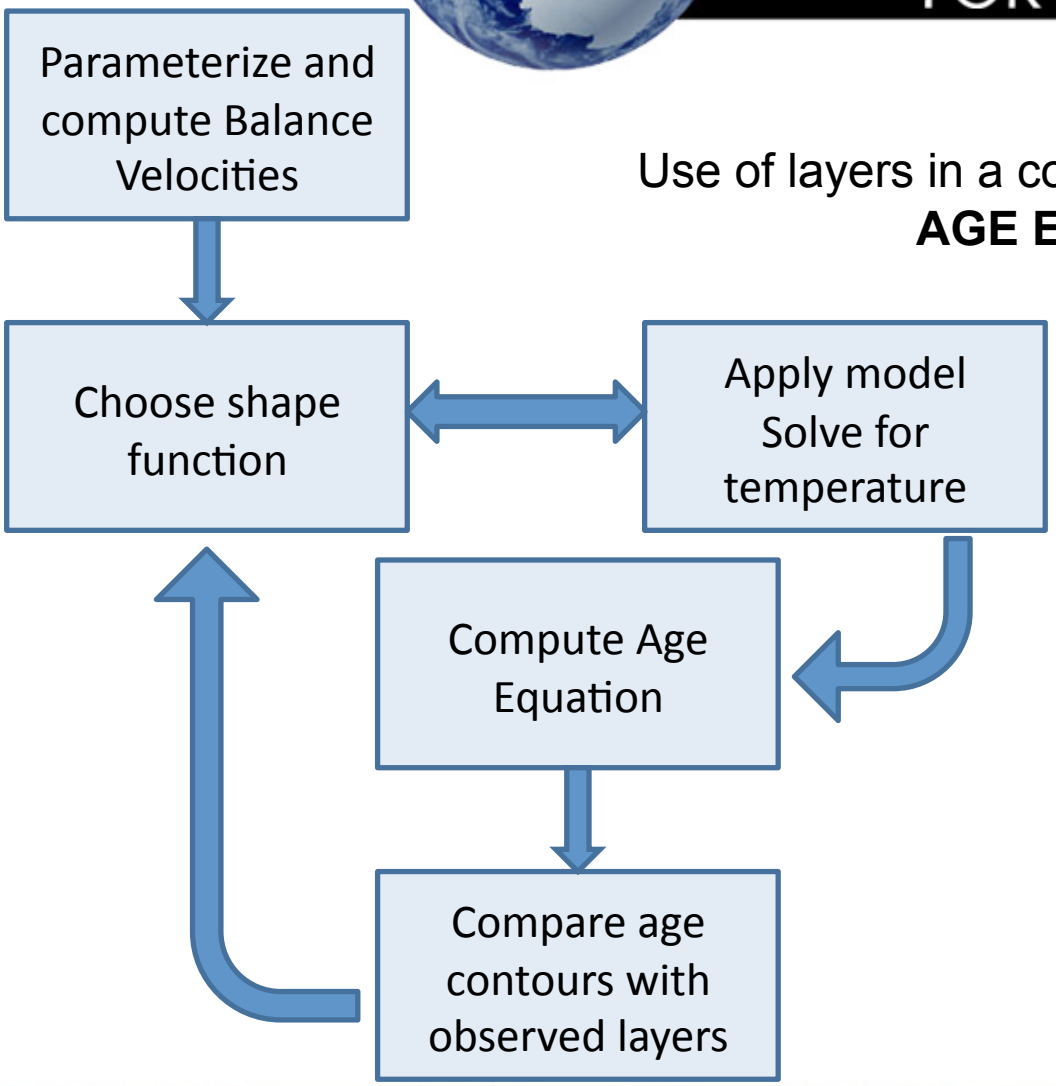
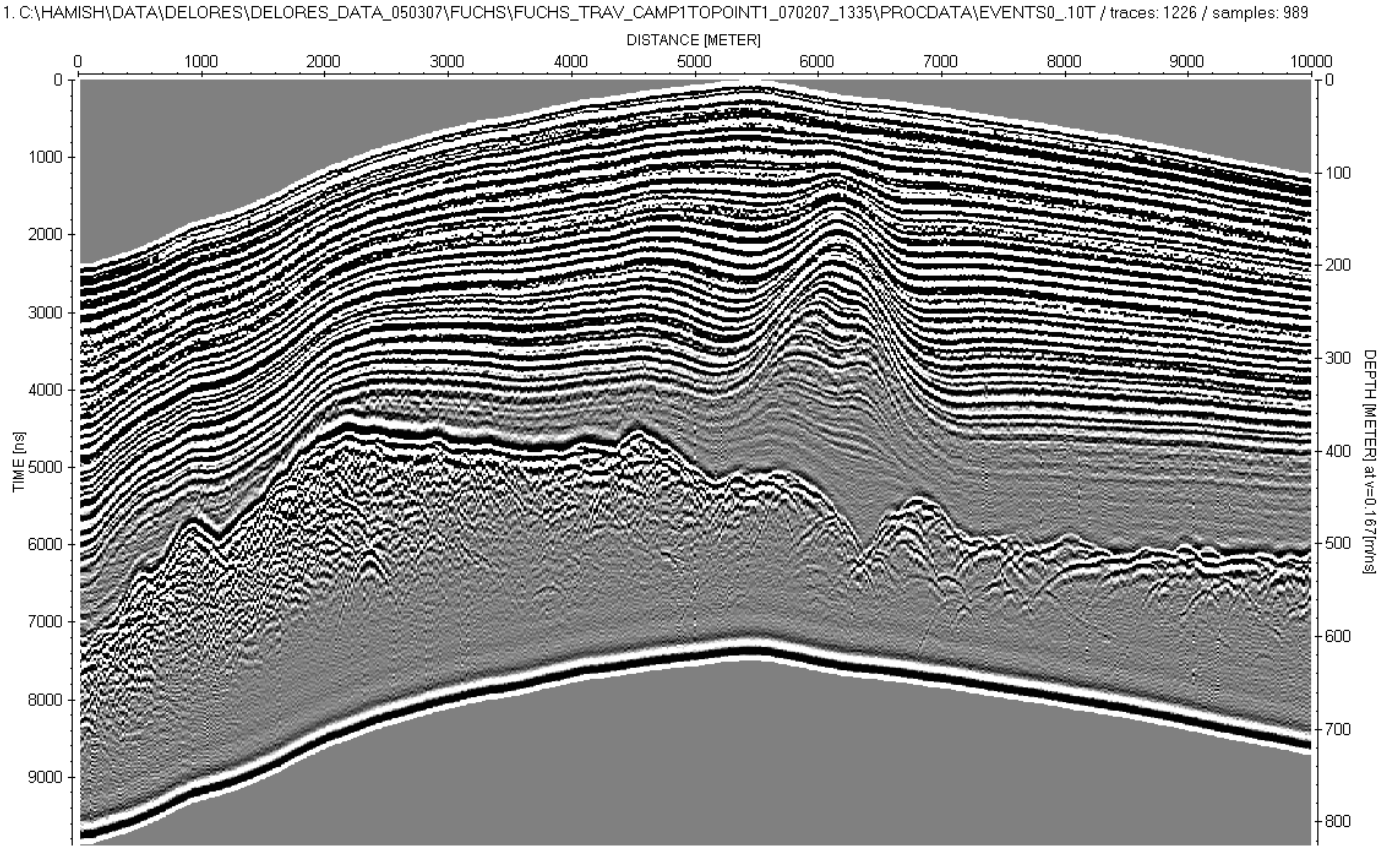
Use of layers in a control model to solve the
AGE EQUATION



Problem: layers are not ‘continuous’ (question of length)
Picking is labour intensive even with automatic (semi) techniques



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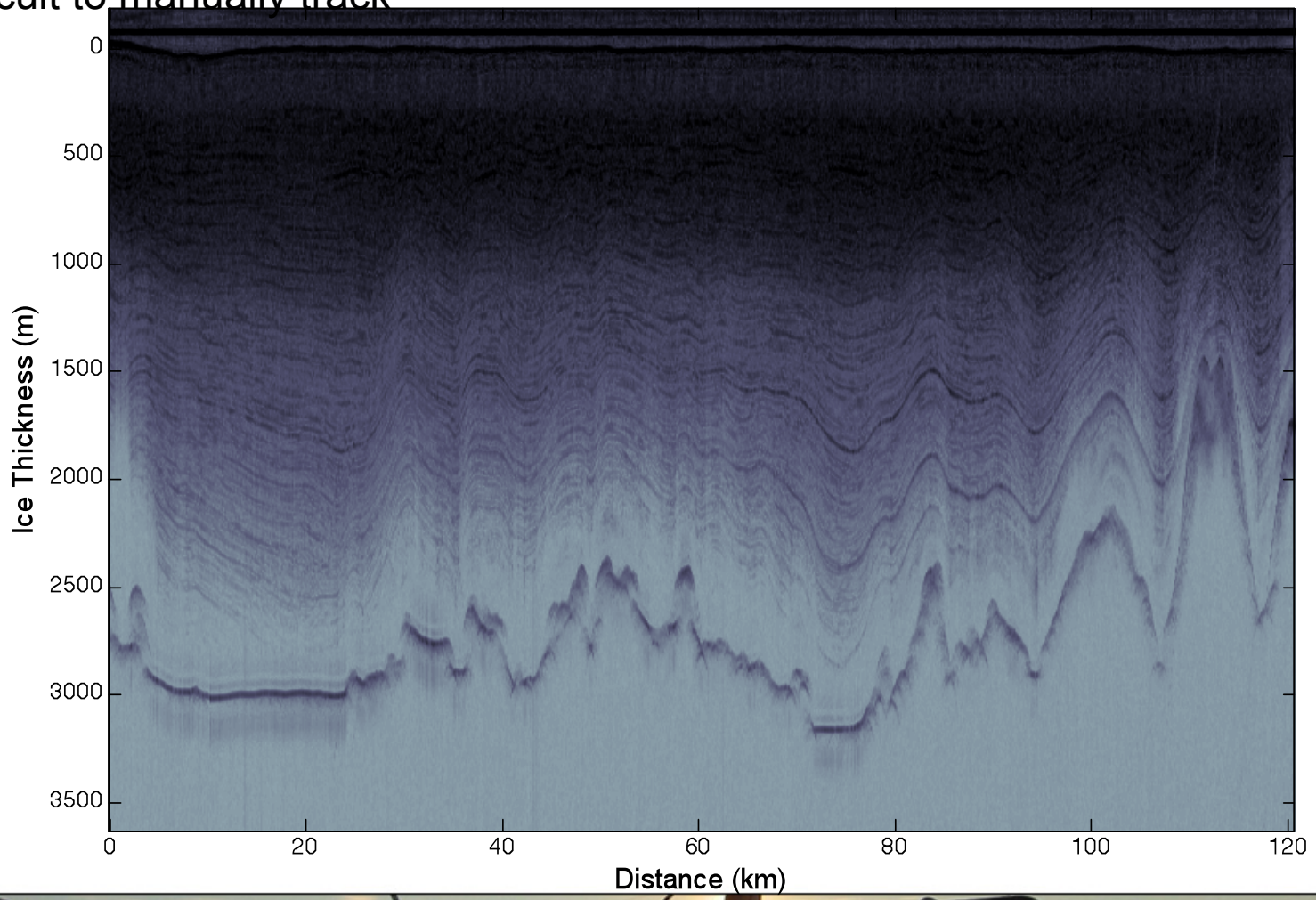
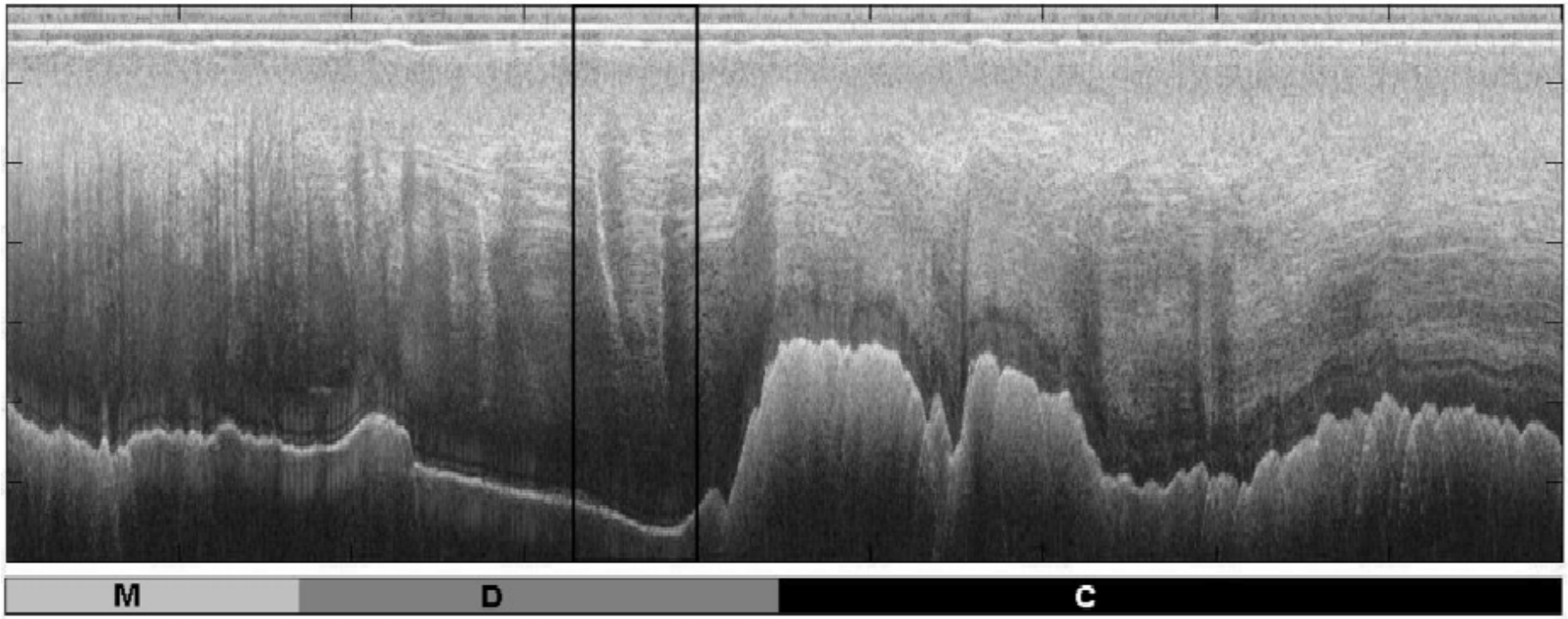
Layers appear continuous
But are difficult to manually track



In regions of fast flow layers are not continuous



45 km section showing M (missing), D (discontinuous) and C (continuous) layering

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Solution: *Parrenin and others (2006)* showed that identical flow information is contained in the apparent dip of the layers.

- Dip datasets can be derived from localised layer information without requiring long-distance layer continuity
- Continuous apparent layer dips can also be integrated to provide synthetic isochrones
- In most circumstances, individually picked layers or continuous sections of apparent layer dip can equally well be compared with model outputs

Parrenin, F., R. Hindmarsh and F. Remy, 2006. Analytical solutions for the effect of topography, accumulation rate and lateral flow divergence on isochrone layer geometry, J. Glacio., 52(177).

They developed a new coordinate transform moving from physical space to a system of (logQ, logω), in which the streamlines are straight lines. Where Q is the horizontal flux and ω is the flux shape function

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The six step automated RES processing method (ARESP)

RES noise reduction

Layer identification

Isolate 'layer objects'

Measure orientation

Eliminate noise

Collate the dip data set

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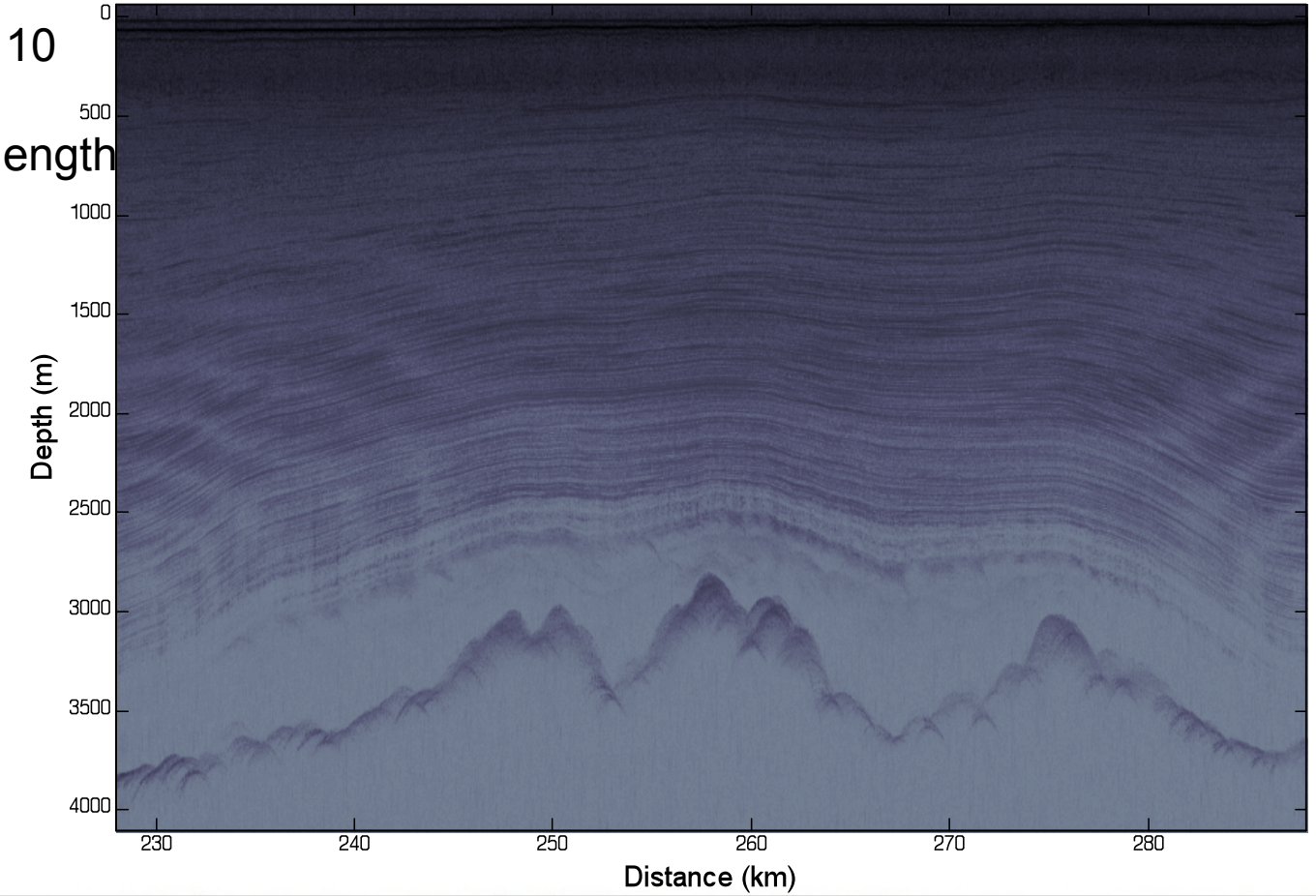
Step 1: *Noise reduction*
Horizontal moving-average window of 100 metres

Decimate by a factor of 10

Vertical averaging with length λ_{layer} /2 to give P_{avg}



Step 2: *Obtain a Binary Layer Dataset*

Directly threshold using a localised threshold

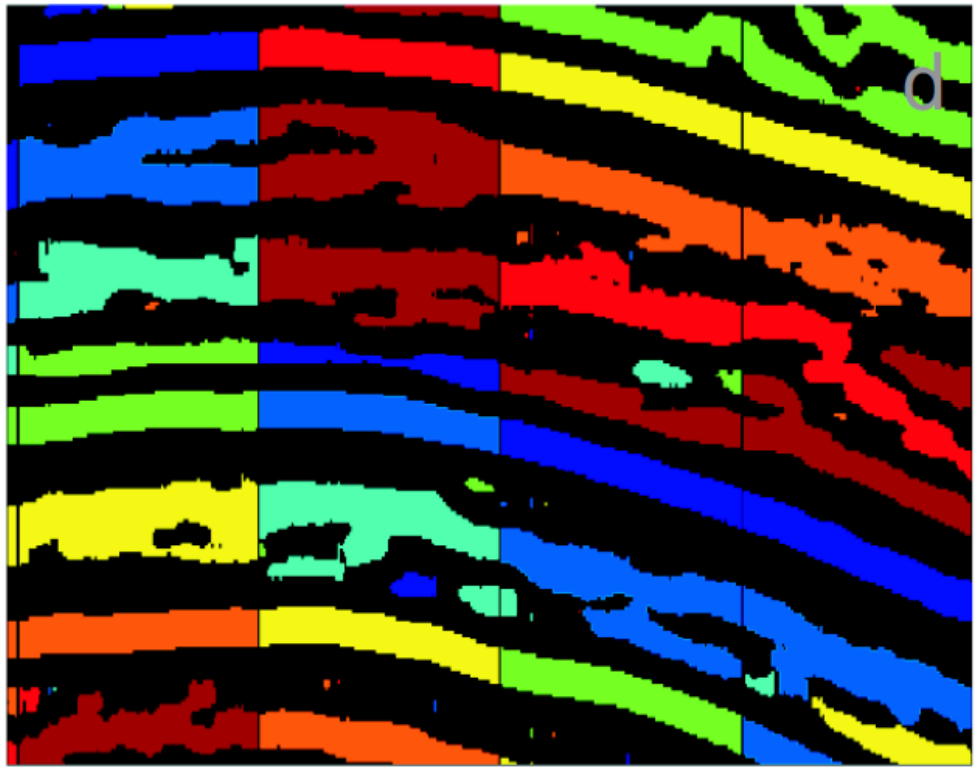
First again vertically average with length (λ_{layer} x 2) to produce P_{avg2}

Then, $B = sign(P_{avg} - P_{avg2})$

Step 3: *Isolate layer objects*

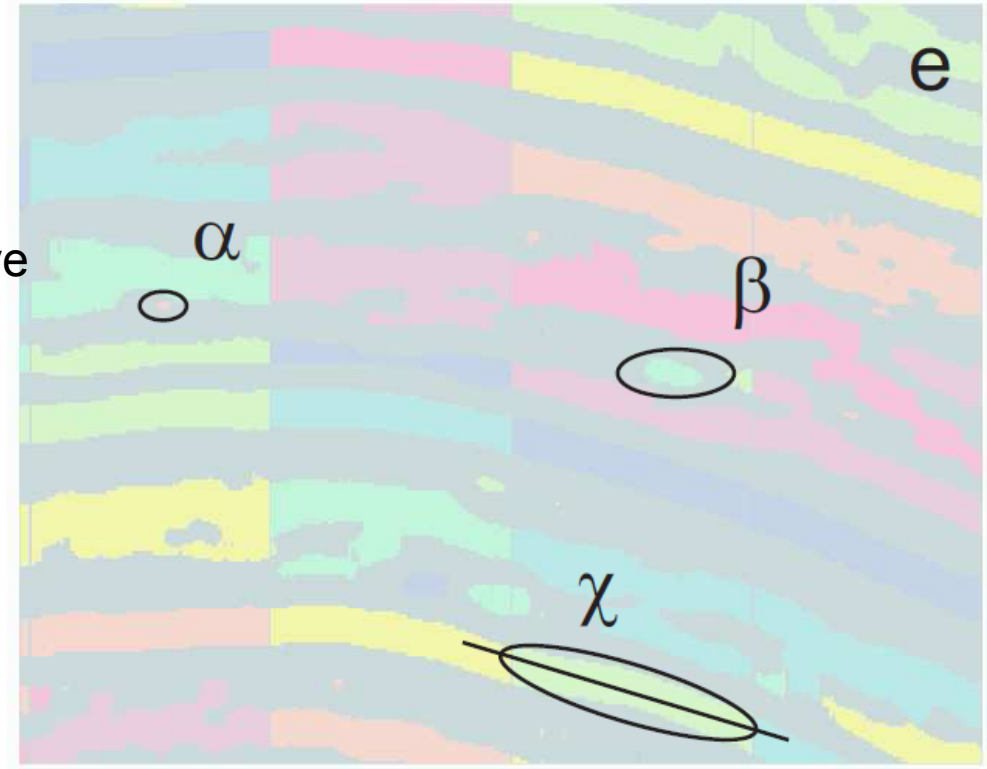
Horizontally separate the binary array into thin vertical stripes *(~ 100 metres)*

An object is adjacent values in a stripe with the same value



Step 4: *Measure 'layer objects*'
Position, area, major and minor axis length, and orientation

Step 5: *Eliminate invalid 'layer objects'*
For example α and β will not give accurate angles



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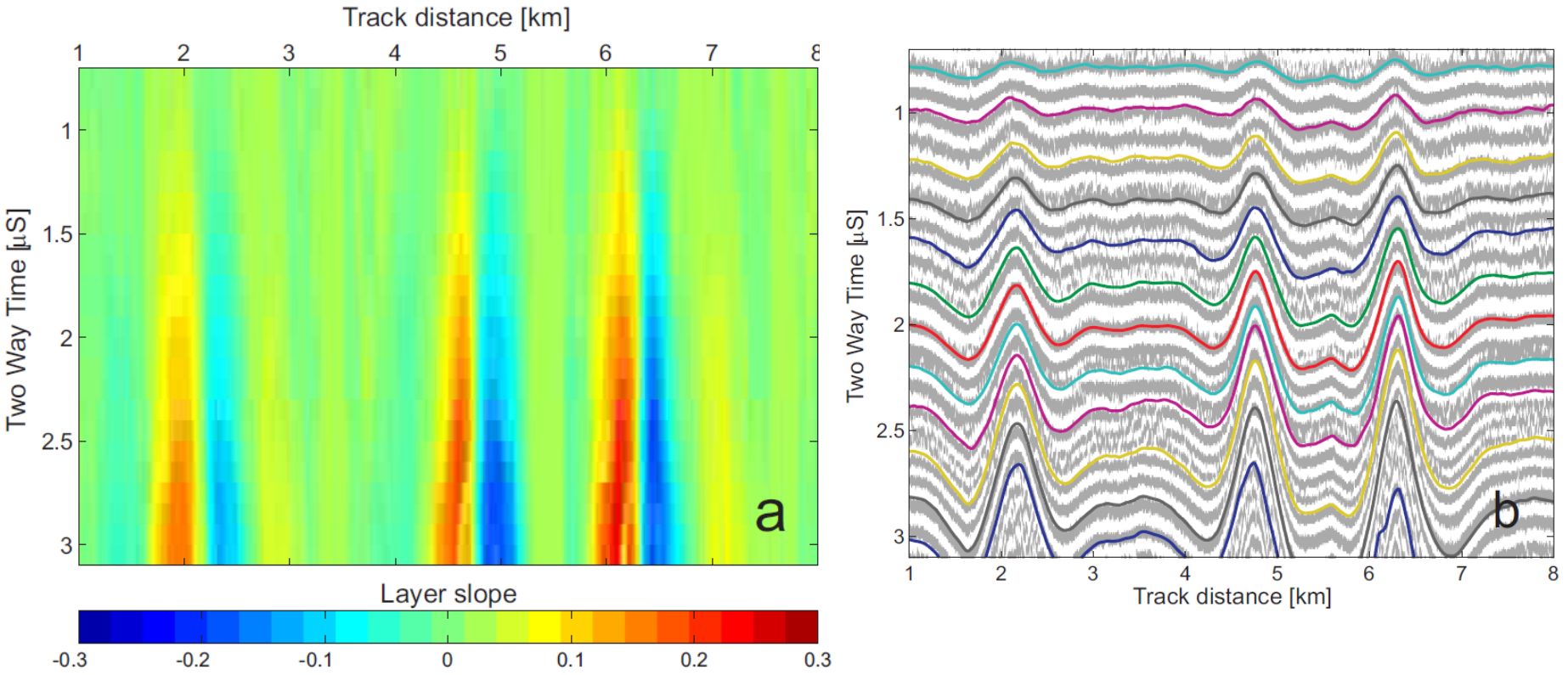
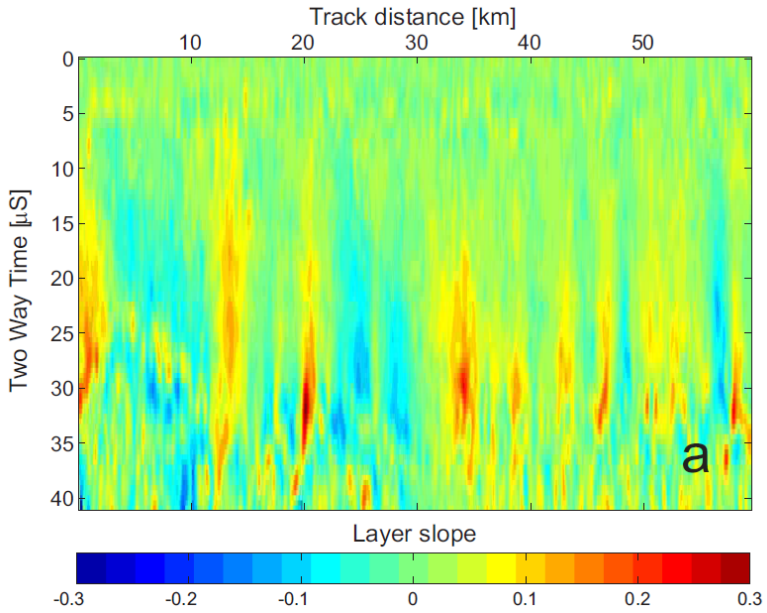
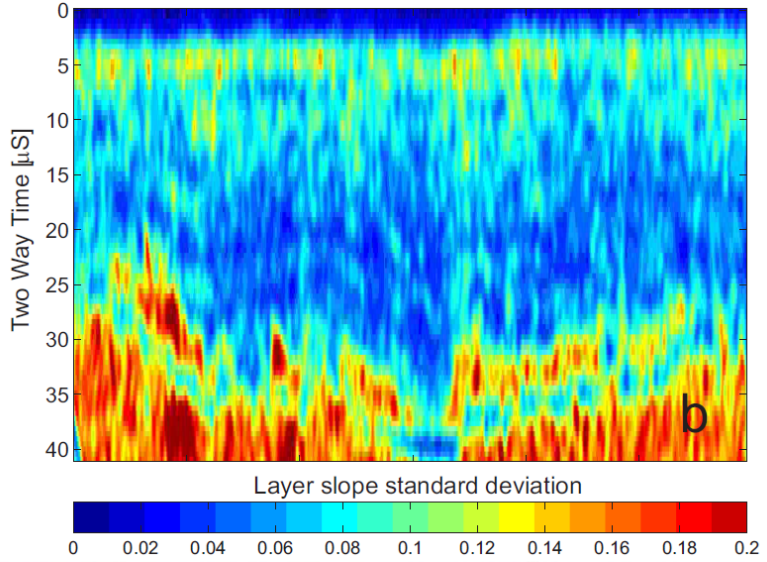


Ground based example. (a) The collated ARESP layer slope data
(b) radargram overlaid with synthetic ‘layers’





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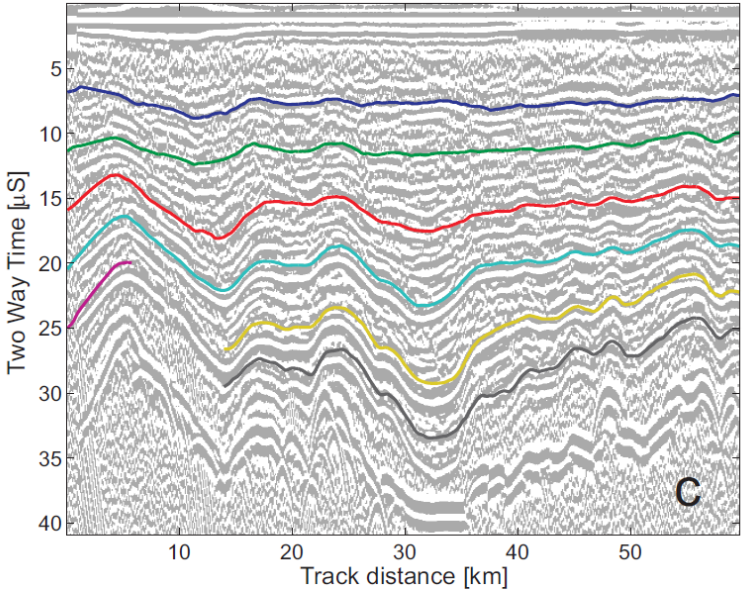
Airborne data example



Note: gray image is a standard score
= (raw – mean)/std

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CONCLUSION

- ARESP is a novel, automated and robust method.

- Continuous layers along the whole length of the RES section are not necessary.

- Because of its efficiency it will enable regional rather than localized studies.

- Work in progress:
  - On the method to automate variable specification for any RES dataset.
  - For direct model-observational comparison or for inverse modelling, there is an issue of how little observational data is required.